Eye-tracking and individual differences in off-normal event detection when flying with a Synthetic Vision System Display

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Abstract

Eye-tracking data were collected on eight pilots who flew a high fidelity flight simulator with a synthetic vision system (SVS) display, which included a tunnel-in-the-sky in half of the experimental conditions. In this paper, we examined the individual pilots' detection and response to two unexpected events, where the true information was inaccurately (or not) represented on the SVS display. The results indicate that the pilots who failed to detect these unexpected events spent most of their time scanning the SVS display, which included the tunnel, and rarely scanned the outside world. The pilot who detected the unexpected events showed scan patterns with a more even distribution of scans to the SVS, the outside world, and other displays even when the tunnel was present. This suggests that detection of unexpected in-the-world events depends on the individual pilot's vigilance in maintaining a regular scan pattern and resistance to "cognitively tunneling" into only one display.

Introduction

Synthetic Vision Systems provide pilots with a realistic 3D image of the terrain in front of the aircraft, with a primary objective of increasing terrain awareness and reducing the likelihood of CFIT accidents (Schnell et al, 2004; Prinzel et al., 2004). The 3-D display format lends itself to the presentation of other relevant information that may impact the flight path of the aircraft, such as a 3-D integrated graphic flight path representation, a tunnel or highway in the sky, designed to aid the tasks of both aviating and navigating (Beringer, 2000; Alexander et al., 2003), and the depiction of traffic in the airspace ahead of the pilot (Merwin, 1998).

The tunnel has been shown to aid routine flight control and, coupled with the presentation of traffic in the SVS, especially those aircraft that occur near the tunnel, to benefit the detection of this traffic. However, the "compellingness" of the tunnel, the very thing that may induce pilots to enter smaller but more frequent control inputs to maintain closer adherence to the flight path, may cause pilots to pay an undue amount of attention to the SVS display and far less to other displays regardless of their relevance to certain tasks (such as detecting outside-world unexpected events). This effect has been defined as cognitive tunneling (Ververs & Wickens, 1998).

Dowell and colleagues (Dowell et al, 2002) suggested that cognitive tunneling may be affected by the compelling nature of HUD symbology superimposed over the flight path, regardless of the relevance of the symbology to the flight task. Wickens et al (1998) demonstrated that cognitive tunneling induced by a HUD caused pilots to miss detecting unexpected events in the environment. In both cases, the cognitive tunneling effect was that attention was focused for an exceptionally long time on the near-domain information (HUD symbology), while the far-domain (outside world) was not given even the minimal amount of attention that it should have received, given that it had infrequent but highly relevant information in the form of unexpected events. The effect is not limited to focused attention to near vs. far domains, however, and has been found to occur in a variety of situations where one source of information contains highly compelling information and other sources of information are ignored, creating a non-optimal information sampling pattern.

In a parallel paper in these proceedings (see Wickens, Alexander, Horrey, Nunes, & Hardy, HFES 2004), we evaluated flight performance, including path keeping and detection of aircraft in the airspace, under a series of display conditions varying the presence of an SVS tunnel, overlaid instrument symbology in the SVS, and out-the-window meteorological conditions to examine the effects of clutter and "compellingness" of the different SVS displays.

In this paper, we are interested in how the presence of a tunnel within the SVS display influences the allocation of attention by the pilots (measured by visual scanning) as this may, in turn, influence the awareness of and response to unexpected events such as the detection of a "rogue blimp," visible in the outside world but not on the cockpit displays, or the detection of a misalignment between the true runway and the SVS depiction of a runway that is 500 ft off the true location. We hypothesize that the pilots who detect these unexpected events will show scanning behavior that includes frequent scans of all of the displays, including the outside world as part of their standard scan pattern, regardless of the compellingness of any one display. Correspondingly, we associate loss of awareness of unexpected hazards as reflecting a form of attentional tunneling that can be directly assessed by scanning.

Methods

Although the full experimental design examined the effects of several display features on several types of tasks (described in more detail in Wickens et al, HFES 2004), this paper focuses only on one hypothesized factor-task effect: namely, the SVS tunnel and its effect on unexpected event (rogue blimp and runway offset) detection.

Participants

Eight instrument rated pilots volunteered for this experiment and were paid $8/hr for their participation.

Displays

A Frasca twin seat flight simulator with 120 degrees outside visual depiction was used. The cockpit was outfitted with a visual display providing an SVS, datalink, instrument panel, and navigation display (see Figure 1). Guidance for the SVS display condition in the tunnel-absent condition is provided by solely by datalink instructions in the bottom box (Figure 1, display A).
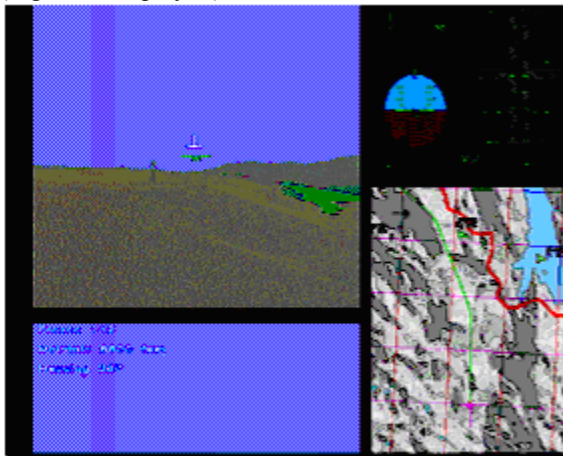
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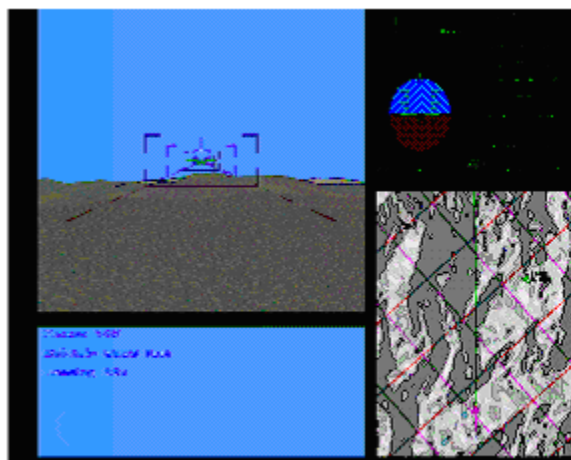
B

Figure 1. Both display conditions. Displays include the Synthetic Vision System (upper left) with or without the tunnel, instrument panel (upper right), datalink (lower left), and navigational display (lower right). Display A is the tunnel-absent condition, Display B is the tunnel-present condition.

The SVS "tunnel-present" condition provided flight path guidance via the preview of a 3-D tunnel in the sky, a depiction of ownship, and a 3-D predictor of ownship 5 seconds into the future (Figure 1, display B).

Procedures and Tasks

Participants flew 8 experimental scenarios of 8-10 minutes each, involving a curved step-down approach through a terrain challenged region to a simulated airport. Pilots were instructed to follow the guidance provided by the datalink display and/or tunnel (if present) as accurately as possible. While flying, pilots were instructed to detect any new traffic that became visible on the SVS display and verbally announce them, and also to report aloud any changes to traffic altitude that they noticed on either the SVS display or the navigation display.

Rogue Blimp Off-normal Event

Each pilot encountered the following off-normal event during one of the eight trials: a "rogue blimp" that was only visible on the outside world, and positioned close enough to the commanded flight path that a maneuver would be required to maintain separation if the pilot was closely maintaining the desired flight path. Pilots were not given any instructions that aircraft might appear in the outside world but not in the SVS, to avoid promoting an atypically high level of vigilance in scanning the outside world. The rogue blimp appeared in the outside world during either the 2nd or 3rd flight trial, near the middle of the trial (prior to the final approach). Four of the participants saw the rogue blimp while flying with the tunnel within the SVS display, while the other four did not have the tunnel. All rogue blimp trials were in visual meteorological conditions.

Runway Offset Off-normal Event

Each pilot also encountered another off-normal event, the runway offset, during one of the eight trials (not the same trial as the rogue blimp). In this case, the pilots were on final approach, preparing to land, and were presented with a depiction of the runway in the SVS that was off-set by 500 ft from the real runway location, which was visible in the outside world. Pilots who noticed the misalignment should have disregarded the inaccurate SVS information and corrected their approach to land on the true, outside world runway, or flown a missed approach. In all cases of the runway offset, the tunnel was present in the SVS and pilots were flying in visual meteorological conditions.

Eye-tracking Data Collection

The pilots wore an Applied Sciences Laboratory eye and head tracking system, so that direction of gaze toward different display "areas of interest" (AOIs, such as the SVS, various instruments, datalink, navigational display and outside world) could be established, and the gaze duration and frequency could be measured as a "percent dwell time" (PDT), our operational measure of the allocation of visual attention.

Results

In the rogue blimp trial, 6 out of 8 pilots appeared (as indicated by their flight behavior) to detect the aircraft in the outside world, and this was confirmed by a closer inspection of the eye-tracking and flight performance data, which provided evidence for both avoidance maneuvers and scans of the outside world that coincided with the rogue blimp's visibility.

Overall detection performance: Rogue Blimp

All four of the pilots in the tunnel-absent condition detected the blimp (indicated by eye-tracking data) and conducted avoidance maneuvers (indicated by control input and path deviation data).

Of the tunnel-present pilots, two detected the blimp and two did not. Figures 2 and 3 represent the segment of time during each trial when the rogue blimp first became visible in the outside world to when it was passed by the aircraft. Figure 2 shows the AOI scanning data for the two rogue blimp detectors in the tunnel-present condition, control input to the aileron and elevator, and the resultant X and Y deviations from the directed flight path. Both of these blimp detectors showed increasingly frequent and long glances to the outside world as the blimp approached the flight path, and control input data show a sharp increase (also evident in the increased path deviations) indicating an avoidance maneuver was conducted. Figure 3 shows corresponding graphs for the two non-detectors in the tunnel-present condition; in both cases, pilots had almost no scans to the outside world (and few away from the tunnel), and did not show any unusual control activity or path deviations, indicating that the blimp was neither perceived nor avoided.

This same pattern in unexpected blimp detection (all tunnel-absent and some tunnel-present pilots detected the blimp) was also shown by the 6 pilots who participated in this experiment but did not provide eye data, as reported in the related Wickens, et al paper.

Percentage dwell times: Rogue Blimp

We then quantified the scanning differences between the three groups of pilots, as measured by their percentage dwell times (PDTs) on each of the two displays most relevant for the off-normal event detection: the Synthetic Vision System (SVS) since it was expected to be the most compelling display, and the outside world (OW) since it contained the true information needed to correctly detect the off-normal events. The PDT data are shown in Table 1.

SVS Percentage Dwell Times			
	Rogue Blimp Detectors		Non-detectors
	Tunnel-Absent	Tunnel-present	
Rogue Blimp Segment	24%	54%	77%
Entire Trial	29%	61%	77%
OW Percentage Dwell Times			
Rogue Blimp Segment	20%	27%	0%
Entire Trial	8%	14%	1%

Table 1. Percentage dwell times for the SVS and the outside world during the segment of the rogue blimp trial when the blimp was visible, and for the rogue blimp trial as a whole.

Analysis of the data collected on the entire trial (bottom row) revealed that non-detectors scanned the SVS display significantly **more** than did detectors (p<0.03) regardless of tunnel presence, and scanned the outside world significantly **less** than did the detectors (p<0.05; refer to Figure 4). This suggests that the two non-detectors were spending most of their time looking at the SVS (77% of the time), and almost no time looking out the window (1% of the time). Detectors, on the other hand, were somewhat more evenly balanced, spending 40% of the time looking at the SVS display and 10% looking out the window (averaged across both tunnel conditions).

During the time frame in which the rogue blimp was visible, the tunnel-absent pilots scanned the outside world (OW) approximately 20% of the time. Evaluation of the scanning behavior of the four tunnel-present pilots for the time frame beginning when the blimp became visible in the outside world to when it would have passed (or impacted) ownship, shows a marked difference in their scanning strategies (refer to Figures 2 and 3). The two tunnel-present pilots who detected the blimp scanned most of the AOIs (those relevant for en route flight) fairly often, including the outside world. By contrast, the two pilots who did not detect the blimp show scanning strategies that rarely included displays other than the SVS, and almost never included scans to the outside world (less than 1%) during this same time frame.

It should be noted that in the rogue blimp trials, tunnel-absent pilots had a much lower percentage dwell time on the SVS display (29%) than tunnel-present pilots (mean 69%; refer to Table 1); further analysis showed that this decrease in SVS dwell times was compensated by an increase in dwells to other display areas such as datalink (the only source of navigation guidance instructions when the tunnel is absent) and the instrument panel. When it is present, the tunnel provides both guidance and current flight information and can be used for effective navigation and aviation in lieu of other displays.

Percentage dwell times: Runway Offset

We next considered the detectors and non-detectors of the runway offset. Since this only occurred within the tunnel condition, their data could be represented in just two groups, as shown in Table 2.

SVS Percentage Dwell Times		
	Runway Offset Detectors	Non-Detectors
Runway Offset Segment	45%	84%
Entire Trial	62%	81%
OW Percentage Dwell Times		
Runway Offset Segment	37%	5%
Entire Trial	13%	3%

Table 2. Percentage dwell times for the SVS and the outside world during the segment of the runway offset trial when the blimp was visible, and for the runway offset trial as a whole.

These data revealed that the percentage dwell times for the detectors and non-detectors of the runway offset are nearly identical to those of the tunnel-present detectors and non-detectors of the rogue blimp (compare Tables 1 and 2).

Finally we note that there was not a perfect identity match between the non-detectors and the detectors of the two off-normal events. In particular, 3 of the 4 pilots who caught the

rogue blimp in the tunnel-**absent** condition missed the runway off-set when the tunnel was **present**. Also, one of the pilots who missed the rogue blimp when the tunnel was present, successfully detected the runway offset, also with the tunnel present. Thus, pilots can be arrayed on a continuum regarding the extent to which they detected both events (Subjects 1 and 4 in Figure 2) or neither event (Subject 8 in Figure 3).

Importantly, when we compared the OW scanning, averaged across all VMC trials for these two best off-normal event detectors with the one poorest detector, we found that the "good" detectors spent 11% **more** time scanning the outside world than the "bad" detector (16% vs. 5%). Correspondingly, when this comparison was made for the SVS scanning, it revealed that "good" detectors spent 13% **less** time scanning the SVS (52% vs. 65%). When only tunnel-present VMC trials are considered, the overall SVS dwell time percentages go up but the difference also increases to 18% (61% vs. 79%); by contrast, OW scanning percentages change only minimally (18% vs. 5%).

Discussion and Conclusions

The combination of eye-tracking data and flight performance data present us with a pretty clear picture of the differences between pilots who may be more likely to see unexpected events that are not presented on the cockpit displays, and those that may be so drawn into a single display that they don't scan the other, potentially highly relevant, displays. These findings are in line with those from Wickens et al (1998) and Dowell et al (2002). The six pilots who missed the off-normal events when the tunnel was present show scan patterns that are similar to each other, and that pattern demonstrates an overwhelming preference to watch the SVS display and virtually ignore the outside world and the instrument panel. This pattern is found throughout the entire trial, and the performance indicates that it clearly does not lend itself to the detection of unexpected events in the outside world.

On the other hand, the pilots who detected the rogue blimp and runway offset show an ability to scan more displays more frequently, especially when the tunnel was absent. Although the overall percentage of scans to the SVS display is substantially higher when the tunnel is present, this "successful" scanning pattern is apparent for the rogue blimp and runway offset detectors in the tunnel-present condition. This indicates that while they scanned the SVS display almost as frequently as the non-detectors, their attention was not as securely captured by the highly compelling SVS display as the two non-detectors were during the critical off-normal detection time.

Attentional tunneling does not seem to occur when there is no compelling tunnel guidance, as evidenced by the tunnel-absent participants' scanning data (Tables 1 and 2). However, this conclusion is based solely on the rogue blimp detection evidence. Since we do not have data on detection of the runway offset in a tunnel-absent condition, we cannot conclude that the SVS alone would not contribute significantly to the cognitive tunneling effects observed in the runway offset trials. There is some thought that it might, due to the

fact that a landing task (when runway offset occurred) has higher associated workload than en route flight (when rogue blimp task occurred), and higher workload has been associated with attentional tunneling (Larish & Wickens, 1991).   In addition, the SVS contained a depiction of the runway during the final approach, which may be as compelling as the tunnel in its own right.

Attentional tunneling may be induced in some pilots when there is a compelling tunnel (compare tunnel-present detectors and non-detectors, Table 1). Clearly, attentional tunneling (measured objectively by scanning patterns) is bad for unexpected OW event detection.

We conclude that while there was a definite overall increase in percentage dwell times for the SVS when the tunnel is present, compared to the tunnel-absent condition, there is still a distinction, based both on performance and eye-tracking data, between pilots who detected the rogue blimp and those who didn't, and that distinction is based squarely on their individual scanning behaviors. What other factors may discriminate the pilots who are sucked in by the tunnel from those who resist its compelling call, we do not yet know.

Acknowledgments

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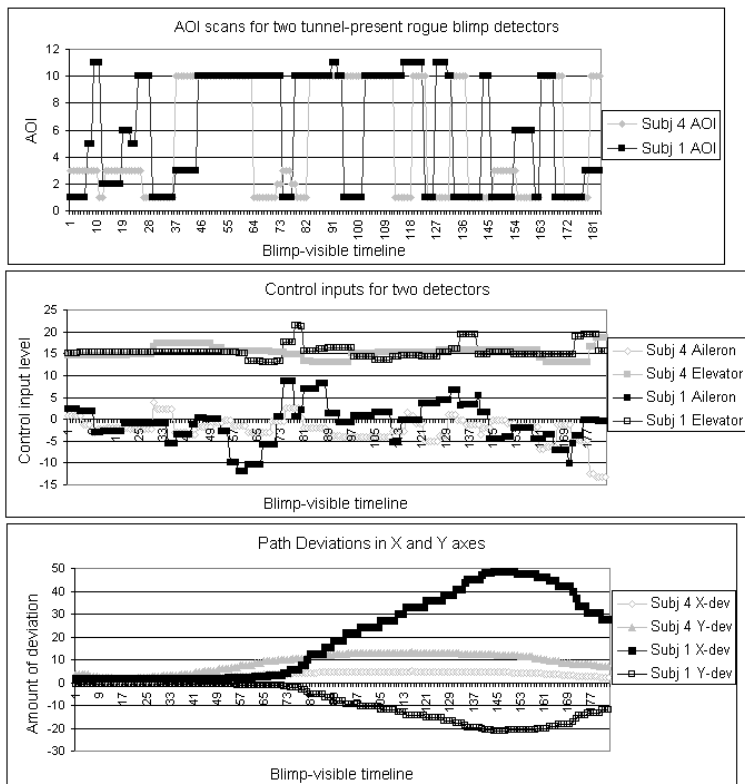
Figure 2. The three graphs represent two detecting pilots' scanning of each display area of interest (AOI), control inputs, and resultant path deviations during the time frame that the rogue blimp is visible in the outside world. In the top graph, AOI 1 is the SVS display, AOI 2 is the datalink display, AOI 3 is the navigation display, AOIs 4-8 are instrument panel displays, and AOIs 9-11 represent the outside world. In the bottom graph, deviations from 0 represent deviations from the ideal flight path.
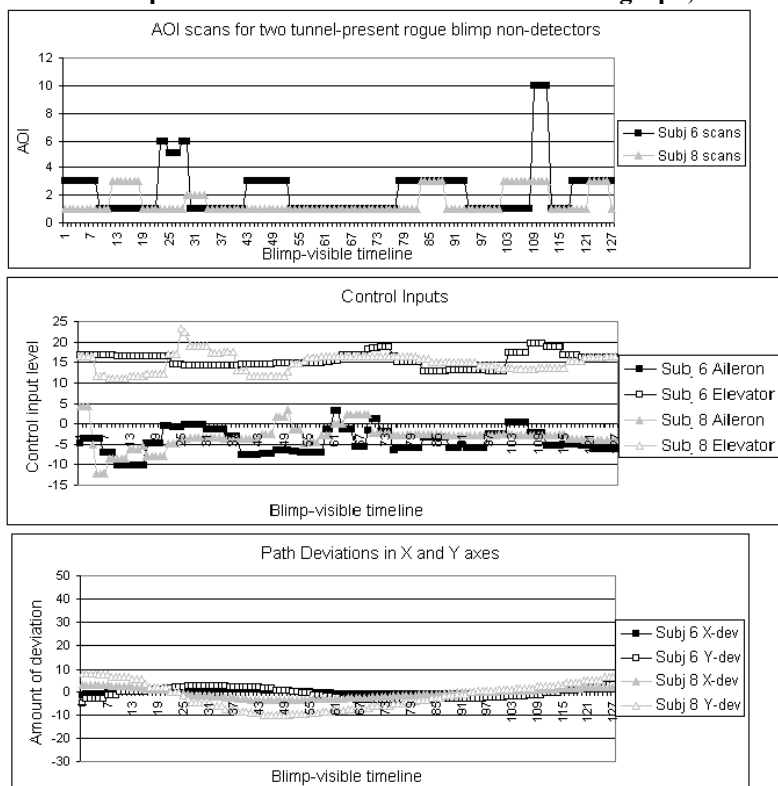

Figure 3. The three graphs represent two non-detecting pilots' scanning of AOIs, control inputs, and resultant path deviations during the time frame that the rogue blimp is visible in the outside world.